SEMI ANNUAL STATUS REPORT

for period ending Sept. 1, 1965
under NASA Grant NsG 367

PERFORMANCE STUDY OF A HIGH ENERGY MOLECULAR BEAM APPARATUS AND MEASUREMENT OF MOMENTUM ACCOMMODATION COEFFICIENTS UNDER SATELLITE CONDITIONS

by

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During this period the last stages of assembly of the high energy beam system have been virtually completed, and most of the components tested. The power supply for the hot tungsten tube source has been changed and the source now operates perfectly up to 2500°K. The responses of the two omegatrons in the beam detection system have been matched and the whole beam detection system including bake-out ovens and translational motion is now operational. The traversing motions for the source operate satisfactorily and complete optical alignment of the entire system is complete. This is particularly important with the heated source because thermal expansions occurring as the source is heated have to be compensated for. Some further details are appended in Section J-1 taken from the 1965 UTIAS Progress Report.

The initial phase of some electron beam studies of the free-jet skimmer interaction has been completed, and the results submitted as a letter to the editor of the Physics of Fluids. The photographs of the density field (see Section J-2 appended) show that no detached shock waves exist in front of the skimmer under the conditions in which maximum skimmer interference is known to occur. Quantitative measurements are now being made using photomultipliers.

The assembly of the test chamber in which the accommodation coefficient measurements will be made is continuing. The target assembly is mounted on a large flange which can be rotated under ultra-high vacuum in order to vary the angle of beam incidence. This flange, involving a flowable indium seat, is nearly complete. The optical lever is in a mild vacuum system outside the bakeable UHV chamber and views the mirror of the target torsional suspension through a UHV sealed optically flat window. The retarding field diode for monitoring the amount of gas adsorbed on the target face, and the electron bombardment system for cleaning the target are being incorporated into the system but have not been checked as yet. Some further details are given in Section J-3 appended.

The survey article "Continuum Source Molecular Beams" written by the principal investigator by invitation appeared in the June 1965 issue of the AIAA Journal, acknowledging NASA sponsorship of the work.

In summary, we are confident of our ability to make the measurements outlined in the original proposal now that our equipment building and testing period is nearly complete. However it may be that the time required will run beyond the end of the three year period (March 1, 1966) and if it becomes apparent by January 1966 that such will be the case we would like at that time to request a no-cost extension of the time to complete the work before issuing a final report.

J. MOLECULAR BEAMS AND SURFACE INTERACTIONS

SUMMARY

The broad objective of the program is to study in depth the factors which influence the interaction between an impinging gas particle and a solid surface, in order to provide physical insight into the boundary conditions that must be used for realistic rarefied gasdynamic calculations. Particular emphasis is being placed on the exchange of momentum and energy (in various forms) for molecular velocities ranging from thermal to satellite flight velocity.

Progress on seven projects over the past year is outlined. The high energy beam facility (Poject J-1) has required a great deal of effort in assembling, testing, and calibrating the many new components but it is now operational again for its forthcoming use in surface studies. The optimization of the performance of this facility is being aided by the auxiliary Project J-2 designed to shed light on the action of the skimmer in the beam formation process. A review of the continuum source molecular beam field has been completed and published in the AIAA Journal, June 1965.

The experiment to measure accommodation coefficients of high energy molecules is now in the assembly stages. Project J-3 describes progress on the optical lever system to be used in making these measurements. In Project J-4 a comparison experiment to measure the scatter patterns of high energy of high molecules from carefully controlled surfaces is described. These two experiments are being set up in interchangeable experimental chambers which both use the high energy beam.

Progress on an ion beam facility is summarized in Project J-5, and was published during the year in UTIAS T.N. 80. An experiment involving the interaction of low energy ions and controlled surfaces is being assembled.

Progress on the development of a method for velocity analysis of a beam of molecules, at velocities higher than those at which mechanical selection is practical, is given in Project J-6. The system has the added advantage of compatibility with ultra-high vacuum requirements and has many potential uses.

Project J-7 arose from the desire to produce a stream of ultra-pure nitrogen for controlled surface studies. The experimental arrangement should provide quantitative information concerning the sticking probability of many gases on fresh nickel films.

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J-1 HIGH ENERGY MOLECULAR BEAM FACILITY - NASA, DRB (H.J. Davis, Jr.)

The purpose of this facility is to produce a well collimated beam of neutral molecules with translational energies from 1 to 10 ev. for use in surface interaction studies. A two component gas mixture is ohmically heated in the source chamber and allowed to expand through a sonic nozzle to form a free jet (see Fig. J-1.1). The centre portion of the jet passes through a conical skimmer into the collimation chamber. The impact probes and velocity selector at the downstream end of the collimation chamber are used to determine the characteristics of the beam. The pair of matched impact pressure probes are connected to the omegatron partial pressure gauges outside the collimation chamber. These probes may be traversed across the beam to measure the radial flux distribution of the component gases in the beam. The rotational velocity selector on the centreline of the beam can measure the velocity distribution of the component gases when used in conjunction with the impact probes.

The past year has been spent in the assembly, testing, and calibration of the various components of the facility. The system to meter the gases introduced into the source chamber was calibrated for helium and argon. When using a sonic nozzle of .013 inch diameter the metering system is capable of producing mixtures from 1 to 10 mole percent argon in helium with source conditions from 100 to 2300 torr absolute and stagnation temperature from 273°K to 2500°K. The carriage on which the tungsten-rhenium source chamber tube is mounted was installed in the low density wind tunnel. The four motor driven motions of the sonic nozzle were tested and found to operate satisfactorily. Initial tests to heat the source were unsuccessful because of the lack of control of the D.C. power supply. This part of the system has been redesigned using a variable transformer for control in series with a fixed transformer to match the resistance of the tungsten-rhenium tube.

After installation of all electrical leads the collimation chamber was leak tested and all safety devices on the pumping system tested.

The assembly of the two impact probes and omegatron gauges has beem completed. (See Fig. J-1.2). The three separate ovens necessary to bake (to 400°C) the entire gauge system have been installed. The traversing assembly for the impact probes and omegatron gauges has been assembled and is operational.

After checking the dimensional accuracy of the velocity selector discs the six discs were stacked together and clamped with the alignment of the slots on adjacent discs corresponding to that required in the final configuration of the discs on the velocity selector motor shaft. Two small holes were machined near the periphery of the stacked discs. These will allow accurate alignment of the discs on the motor shaft. Design, construction and preliminary testing was completed on the photo diode circuit which supplies signals to the electronic counter used to determine the rotational speed of the velocity selector. The variable frequency power supply for the velocity selector was modified by the addition of safety features to insure the selector cannot by run faster than the 20,000 rpm maximum operational speed.

Work is now being done to match the response of the two omegatron tubes.

J-2 ELECTRON BEAM STUDIES OF SKIMMER INTERACTION IN A FREE JET - NASA, DRB (G. E. McMichael)

This work is complementary to that reported in J-1 and is being performed to obtain information necessary for the optimum design of skimmers for use in continuum source molecular beams. Qualitative density maps have been obtained of the region in front of a skimmer located on the centre line of an argon free jet. The flow visualization technique used is to hold the camera shutter open while a diametral "cut" of the density field is painted in by moving a transverse electron beam steadily downstream.

To obtain sufficient resolution, a conical skimmer with a 0.104 inch diameter orifice was used. The skimmer had external and internal half angles of 35 and 25 degrees respectively, and the source orifice diameter was 0.031 inches. Figure J-2.1 shows the apparatus mounted in the UTIAS low density tunnel. By varying the source stagnation pressure from 120 to 2400 torr, and the nozzle-skimmer distance from 1.0 to 0.31 inches (32.3 to 10.0 nozzle diameters) it was possible to vary the skimmer Knudsen number (based on a hard sphere model mean free path) from 1.1 to 0.0053. This is the region over which it has been proposed that there is a detached bow shock in front of the skimmer. When the region behind the skimmer was sealed off so that the flow stagnated at the skimmer orifice, a detached bow shock was observed. However, in all cases, when the pressure behind the skimmer was reduced to that of the tunnel background pressure (3-30 microns depending on the source stagnation pressure) a shock was observed attached to the skimmer, but there was no apparent increase in density in the region directly in front of the skimmer orifice. An example of the two cases is given in Fig. J-2.2.

Modifications are now being made in order to make a quantitative study of this same region using a photomultiplier to measure the light intensity. Calculations indicate that the achievable sensitivity will match that necessary to detect the density of a reflected cloud of molecules capable of any appreciable beam attenuation. Provision is being made to examine the interesting region just inside the skimmer.

J-3 OPTICAL LEVER FORCE AND ENERGY TRANSDUCER - NASA, DRB (E. J. Moskal)

The object of this project was to develop an instrument to be used for momentum accommodation coefficient studies in the high energy molecular beam facility. It will be necessary to measure accurately forces of the order of 10^{-5} to 10^{-6} dynes.

Final calibration of the optical lever (see Fig. J-3.1) was accomplished during the past year. A primary calibration system which gives a direct, known rotation of a mirror, is used to calibrate a secondary calibration system which remains on the lever. This secondary system will be used to check the sensitivity of the lever before each experimental run. Figure J-3.2 is a segment of a secondary calibration trace, illustrating the good linearity obtainable. Linearity provides a good indication of the quality of the grids and the optics. The output of the optical lever is linear over a range corresponding to 7.5×10^{-4} radians.

From Fig. J-3.3 one can see that at a maximum sensitivity, (with a fixed mirror), the ultimate noise level of the optical lever in vacuum was approximately equivalent to a mirror rotation of 1×10^{-8} radians. This noise level is primarily due to the inherent noise at the photoconductive cells. The long term drift from all sources was found to be 1.54×10^{-8} rad/min.

If one uses a torsion balance having an 0.001" diameter tungsten wire, one can expect a rotation of 1.65×10^{-5} radians for a force of 10^{-5} dynes. As the noise level of the lever is 10^{-8} radians, and the detection system is linear over at least 7.5×10^{-4} radians, then expected forces of 10^{-5} to 10^{-6} dynes can be measured with the existing optical lever, since the expected mean Brownian excursion of the balance is approximately 1.6×10^{-7} radians. Studies are continuing on the best damping and nulling methods.

The optical lever is now being adapted for use in measuring momentum accommodation coefficients of argon and nitrogen on the (100) face of tungsten and nickel. The basic components for this study have been obtained and machining has started on parts of the apparatus. The system consists of a 500 litre/sec Triode-getter ion pump with a bakeable stainless steel chamber mounted on it. A rotatable UHV top has been designed for the experimental chamber, and is now being fabricated.

J-4 SCATTERING OF HIGH ENERGY MOLECULES FROM SURFACES - DRB (D. R. O'Keefe)

An experiment designed to study the reflection of high energy (1 to 10 ev) argon atoms from target surfaces of tungsten and nickel is being assembled. In particular, the experiments will be performed on the (100) single crystal faces of these materials. Tungsten and nickel have been chosen because they are compatible with ultra high vacuum ($< 10^{-8}$ torr) requirements and can be heated to elevated temperatures for cleaning purposes. Crystals have been purchased in which the orientation is within $\frac{1}{2}^{\circ}$ of the normal to the surface. A relatively smooth microscopic surface has been achieved through the process of electropolishing. As is already known from low energy electron diffraction studies, heat treatment in vacuum will further perfect the surface. Various tests are being set up to provide the best possible knowledge of the microstructure of the surface.

A two axis crystal-orientation device (Fig. J-4.1) has been built which allows changes in the angle of incidence of the incoming beam, as well as a rotation about the beam axis to allow the complete 3-dimensional scattered flux distribution to be obtained.

The detector is a G.E. Type 22PT120 bakeable mass spectrometer used in the stagnation pressure measuring mode. The positioning device for this unit has been completed and is ready for installation in the bakeable stainless steel test chamber. The system is provided with a 500 l/sec triode gettering pump. It is estimated that the pressure will be approximately 10^{-9} torr in the interaction chamber with the beam on. As the stagnation pressure due to the reflected molecules is typically 10^{-11} torr, it is necessary to improve the discrimination of the reflected molecule signal as measured by the detector, from the "noise" due to the background pressure. To accomplish this, a pill-box cryogenic region has been designed and built to surround the target. It consists of a liquid helium stainless steel dewar completely surrounded by a larger but similarily constructed dewar of liquid nitrogen. Feed lines pass through the vacuum wall and the liquid levels are maintained by commercially purchased liquid level controls.

With the use of such high energy beams, it is believed that the sticking probability of gases leaving the target and impinging on the liquid helium cooled wall, will be something less than unity (no values of the sticking probability for relatively energetic molecules are available to date). To greatly reduce the possibility of having these partially accommodated molecules come off the cryogenic surface and interfere with the detector signal, a serrated surface (Fig. J-4.2) has been constructed for the inner surface facing the target. The plate is bent into a circular cylinder with the finned surface towards the centre and with each of the fins skewed a tan angle of 30 degrees to the radius so that most of the molecules suffer multiple collisions with this wall. The true reflected signal as measured by the detector is then unhampered by the pressure of slower moving molecules from other parts of the system.

Most of the electronic support equipment has been obtained, including a retarding field diode unit to monitor the surface potential of the crystal surface. This will provide a measurement of the state of cleanliness of the crystal. An electron bombardment power source has been constructed for use in cleaning the target. Before actual experiments can be conducted, final mechanical assembly is required as well as a calibration of the detector.

J-5 INTERACTION OF LOW ENERGY IONS WITH CONTROLLED SURFACES - ONR, DRB (R. H. Prince)

The production of high-energy molecular beams by means of charge-exchanged ion beams is entirely feasible; however, it is felt that there is much to be learned by a study of the nature of the interaction of the ions themselves with surfaces of known properties. Of particular interest in many fields of plasma physics and thermonuclear physics is the production of secondary electrons and the reflection of primary ions. The proposed experiment is concerned with the measurement of the total yield, energy spectrum, and spatial distribution of secondary particles as a function of ion energy and angle of incidence. The ion energies of interest (5 to 20 ev for N^{+}_{2}) are such that the radiationless (Auger) transitions responsible for secondary emission do not directly involve the translational energy of the incoming particle, but principally the ionization potential of the gas and the conduction-band parameters of the solid. Experimental data for gases other than the inert ion species is non-existent below 50 ev., at which energy it is apparent that in order to reconcile the reduced yield of a diatomic species compared to that of an inert gas of similar ionization potential (e.g. N_2, Ar) one must postulate an energy sink, possibly molecular vibration as proposed by Propst and Luscher. A theoretical calculation of the secondary-electron energy spectrum and spatial distribution has commenced, attempting to include the proposed vibrational final states; it is felt that the fitting of the theory of these measurable functions will provide an insight into the process.

The experimental program is naturally concerned initially with the production of an ion beam of maximum intensity and purity, combined with minimum energy deviation, in the energy range of interest. A preliminary facility was outlined in the previous (1964) Progress Report, and is described in detail in UTIAS Technical Note No. 80. At that time, it became evident that before performing a definitive experiment modifications would be necessary, namely the elimination of undesired ion species and excited neutral particles by means of mass-sensitive deflection, and the use of controlled surfaces in a high-vacuum environment.

A schematic diagram of the apparatus is shown in Fig. J-5.1. Clearly seen is a Nier-type mass spectrometer of 60° deflection, designed for operation at up to 1 kilogauss; flux density profiles obtained using a Hall-effect probe, show a high degree of homogeneity ($<.1\%$ deviation) over the portion of the ion path within the pole pieces. The vacuum enevelope has of necessity been modified simultaneously, with the ion optical system, to accommodate the spectrometer stage. The 18" dia. bakeable experimental chamber has been fabricated, and a General Electric 100 litre/sec Triode getter ion pump purchased to provide a calculated environmental pressure during beam operation of 10^{-9} torr. Consideration is presently being given to the control and measurement techniques required for study of the surface interaction. A Cary vibrating-reed electrometer will be used as a detector, in conjunction with a simple low noise differentiating circuit consisting of Philbrick P-65A solid-state operational amplifiers, which are battery operated, permiting floating operation.

J-6 PULSED ELECTRON BEAM VELOCITY ANALYSER - ONR, DRB (J. W. Locke)

This is a development project intended to assess the merits of an all-electronic technique for measuring the distribution of molecular velocities in a low-density gas stream. The instrument is based on measuring the time taken by molecules of the original gas stream that have been excited by electron impact to travel a known distance to a detector placed downstream. Of the many products created in the gas by electron impact, molecules in long-lived (metastable) excited states are the most suitable for this measurement because, unlike ions, they carry no electric charge and are not accelerated by the strong electric fields associated with the electron beam producing the excitation. Because there are no moving parts in this type of analyser, it is well suited to the velocity analysis of high speed molecular beams (10,000 metres/sec. and higher), and to ultra-high vacuum systems.

Work to date includes the design and construction of a classical molecular-beam source, the construction of a two-chamber (excitation and detection) vacuum system, a high voltage pulser to drive the electron beam system used for the excitation and an electron-ejection detector with associated circuitry. System diagrams can be found in the 1964 Progress Report. Work on the detector continues.

The schematic of the high-voltage pulser is presented in Fig. J-6.1 and a photograph of the completed pulser in Fig. J-6.2. This pulser has driven the high-power electron gun at 17 KV., 400 ma. with 1 μ sec. risetime, more than sufficient for this experiment.

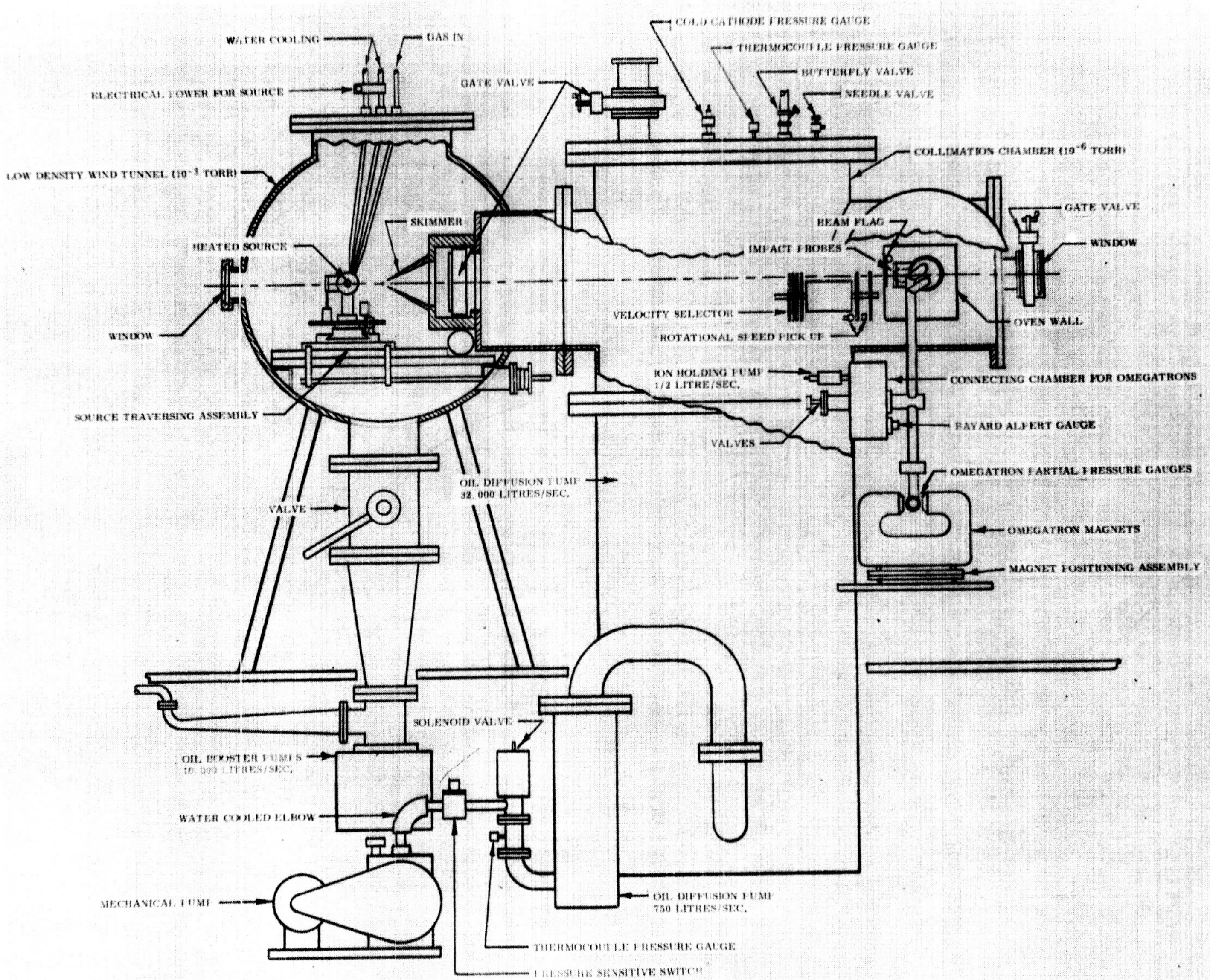


FIG. J-1.1 SCHEMATIC OF HIGH ENERGY MOLECULAR BEAM FACILITY

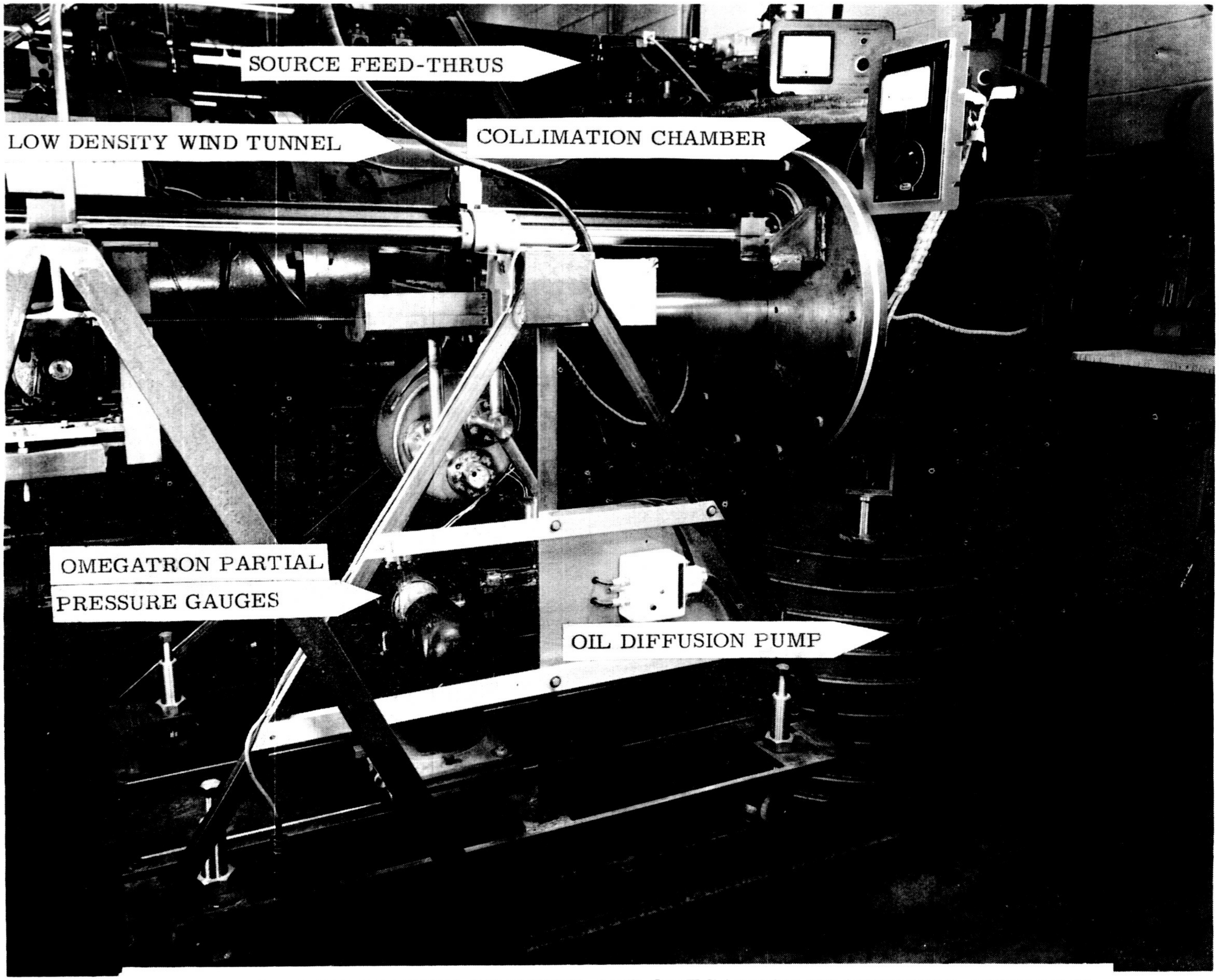


FIG. J-1.2 COLLIMATION CHAMBER AND OMEGATRON TRAVERSING ASSEMBLY

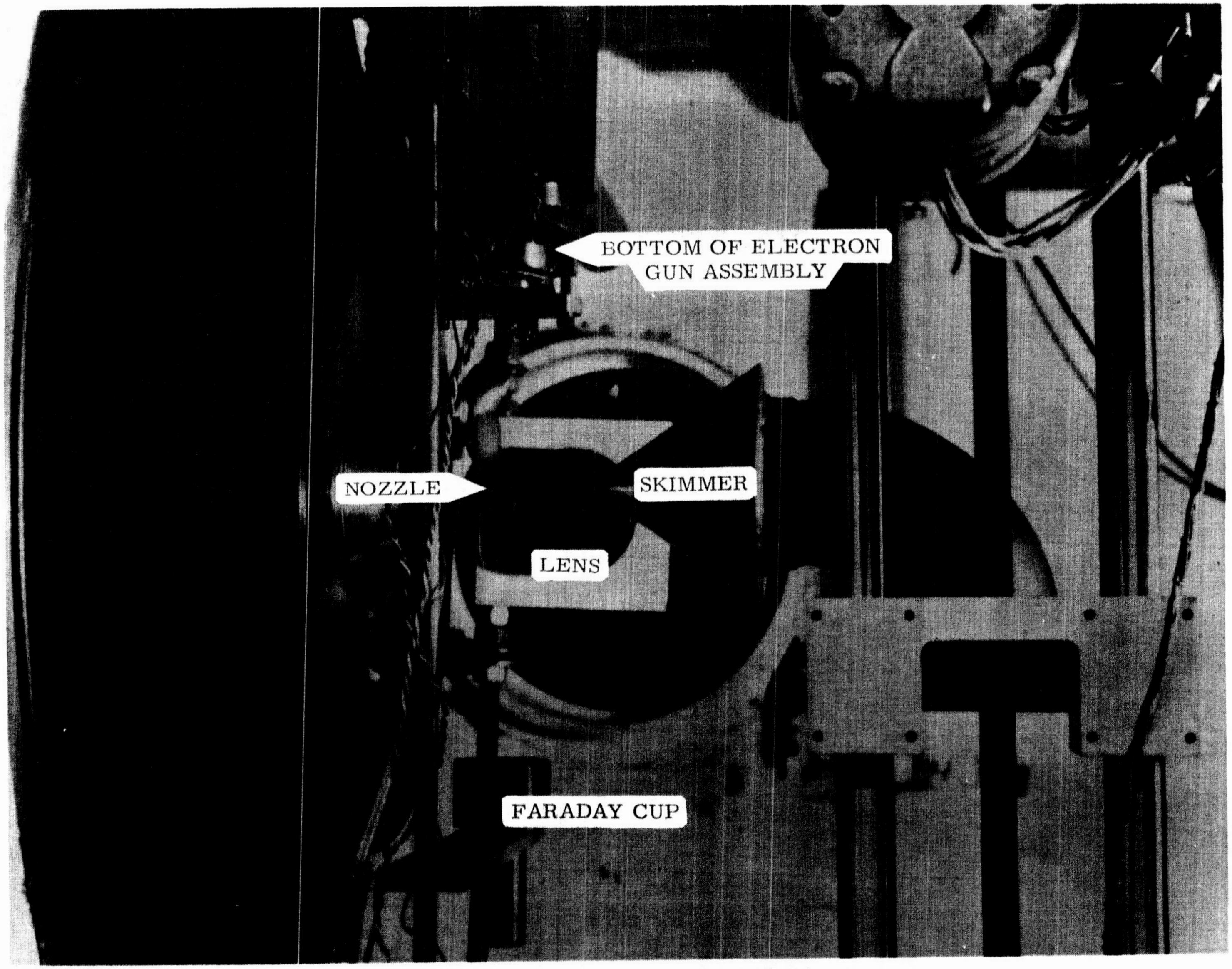
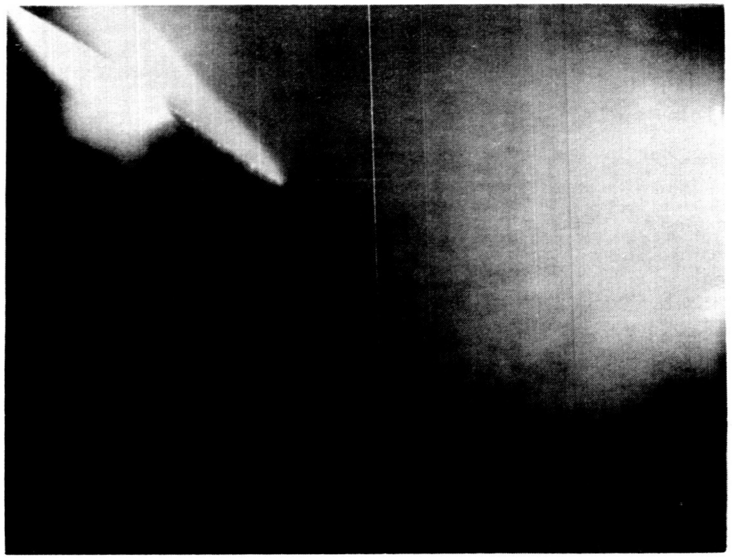
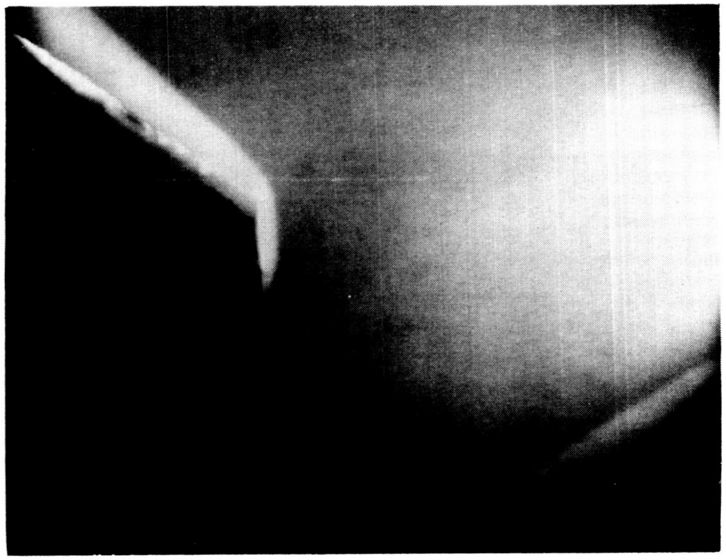

BOTTOM OF ELECTRON
GUN ASSEMBLY
NOZZLE
SKIMMER
LENS
FARADAY CUP

FIG. J-2.1





PUMPED

STAGNATED

ARGON $T_o = 298^oK$ $d_o = 0.031''$ $d_s = 0.104''$

$P_o = 2400$ torr $Kn_s = 0.0308$

$\frac{x}{d_o} = 24.2$ $M_s = 27.9$

FIG. J-2.2

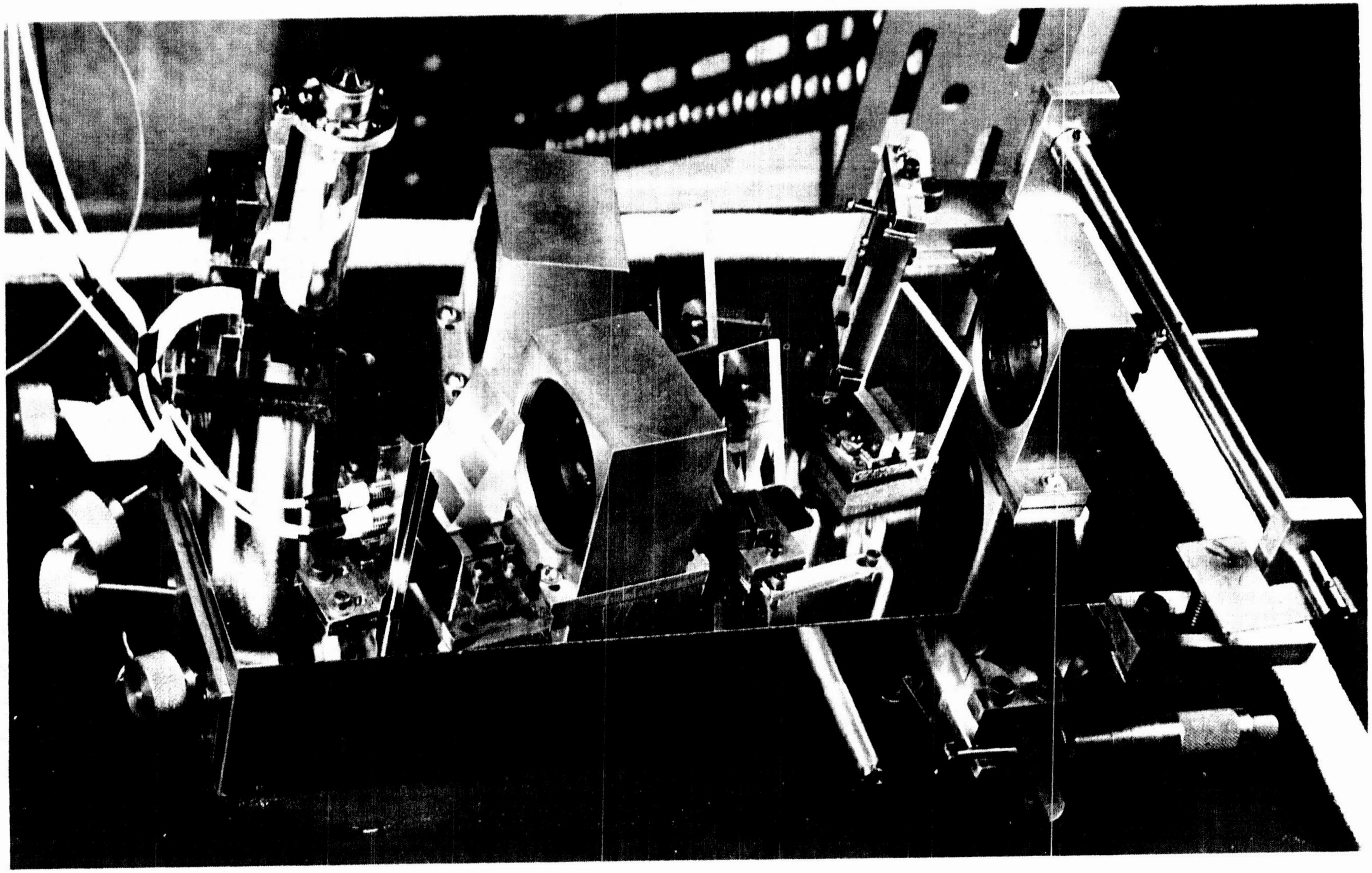
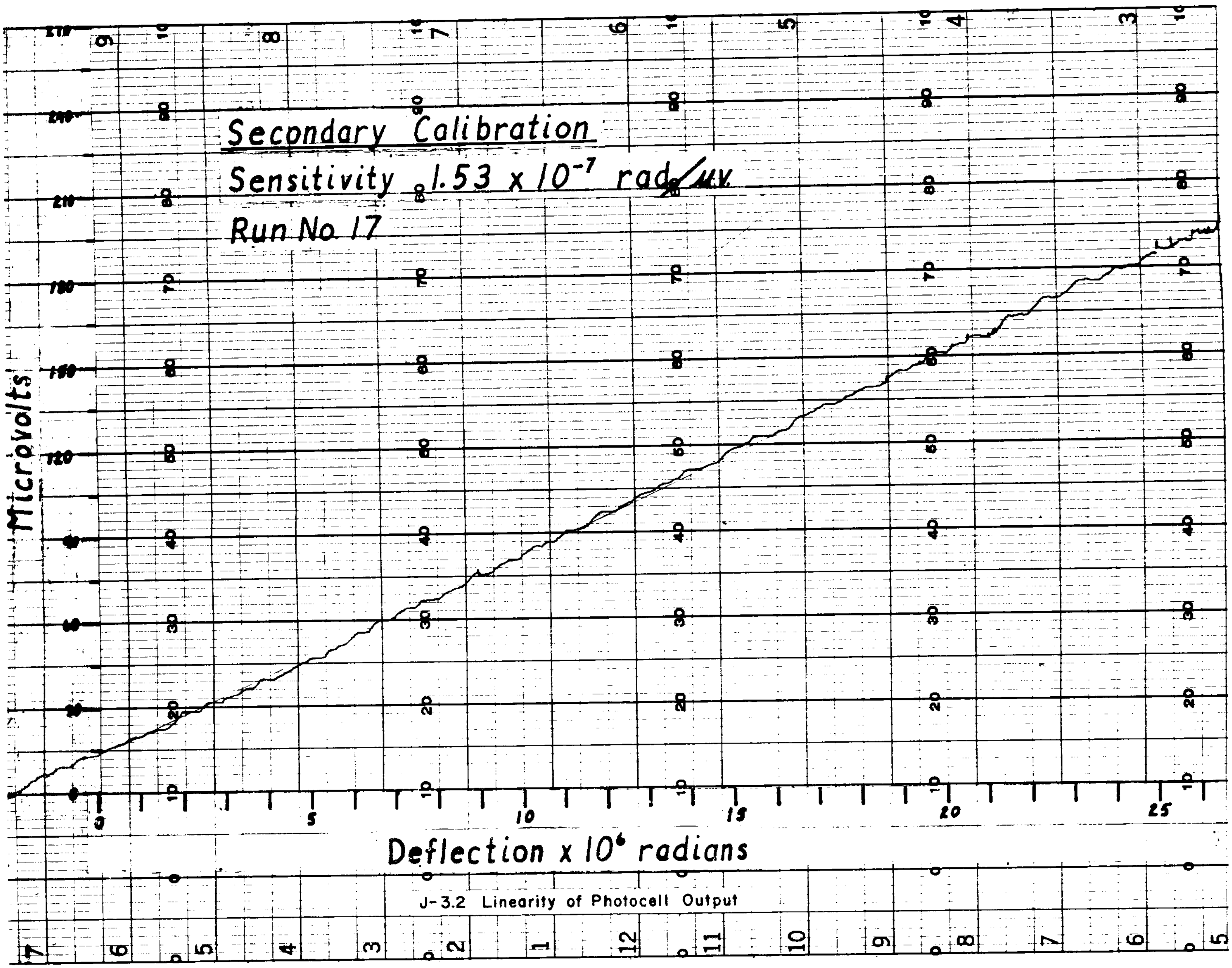
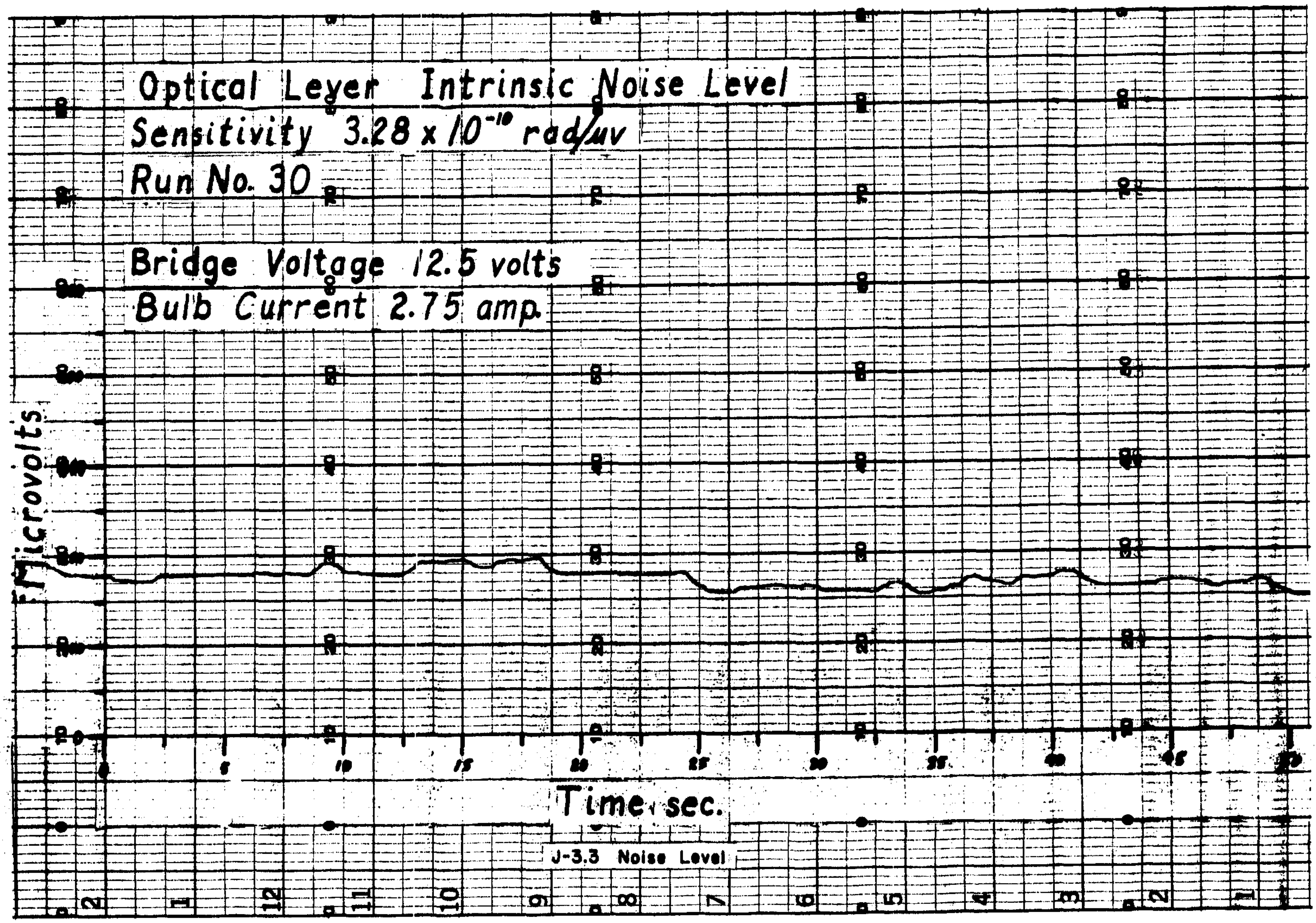


FIG. J-3.1 OPTICAL LEVER ASSEMBLY



J-3.2 Linearity of Photocell Output



J-3.3 Noise Level

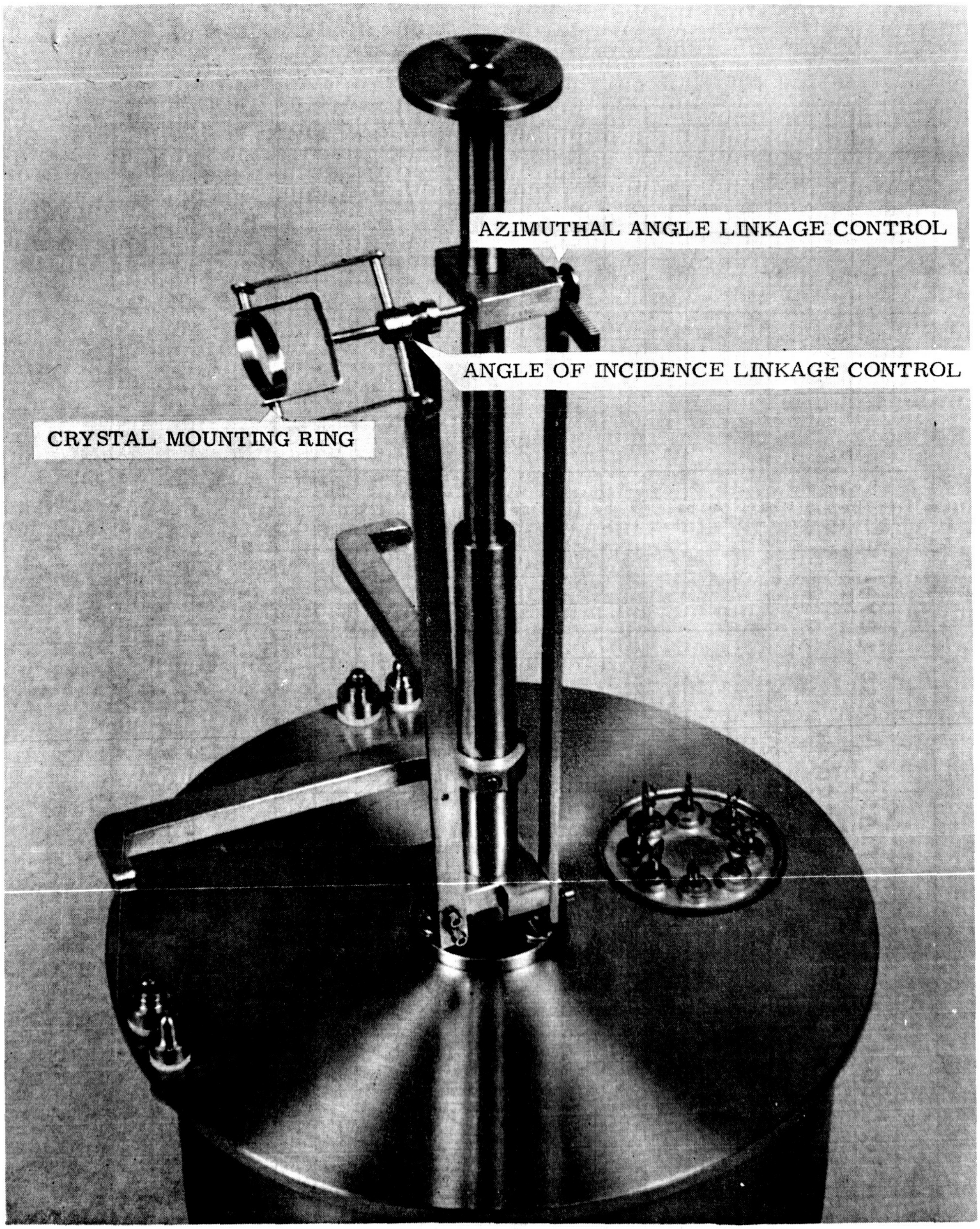


FIG. J-4.1 CRYSTAL TARGET ORIENTATION DEVICE

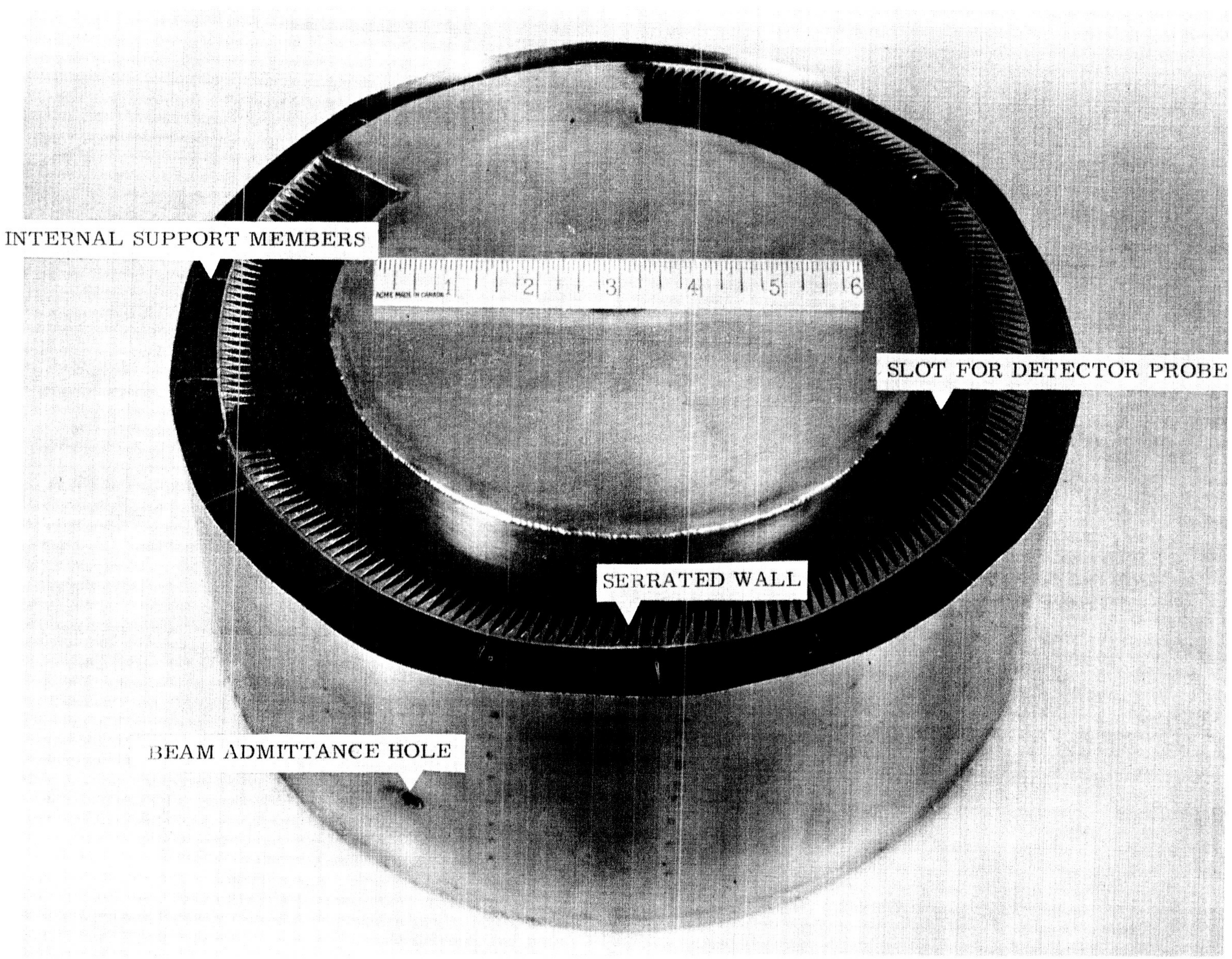


FIG. J-4.2 CRYOGENIC (LIQUID HELIUM) PUMP SYSTEM

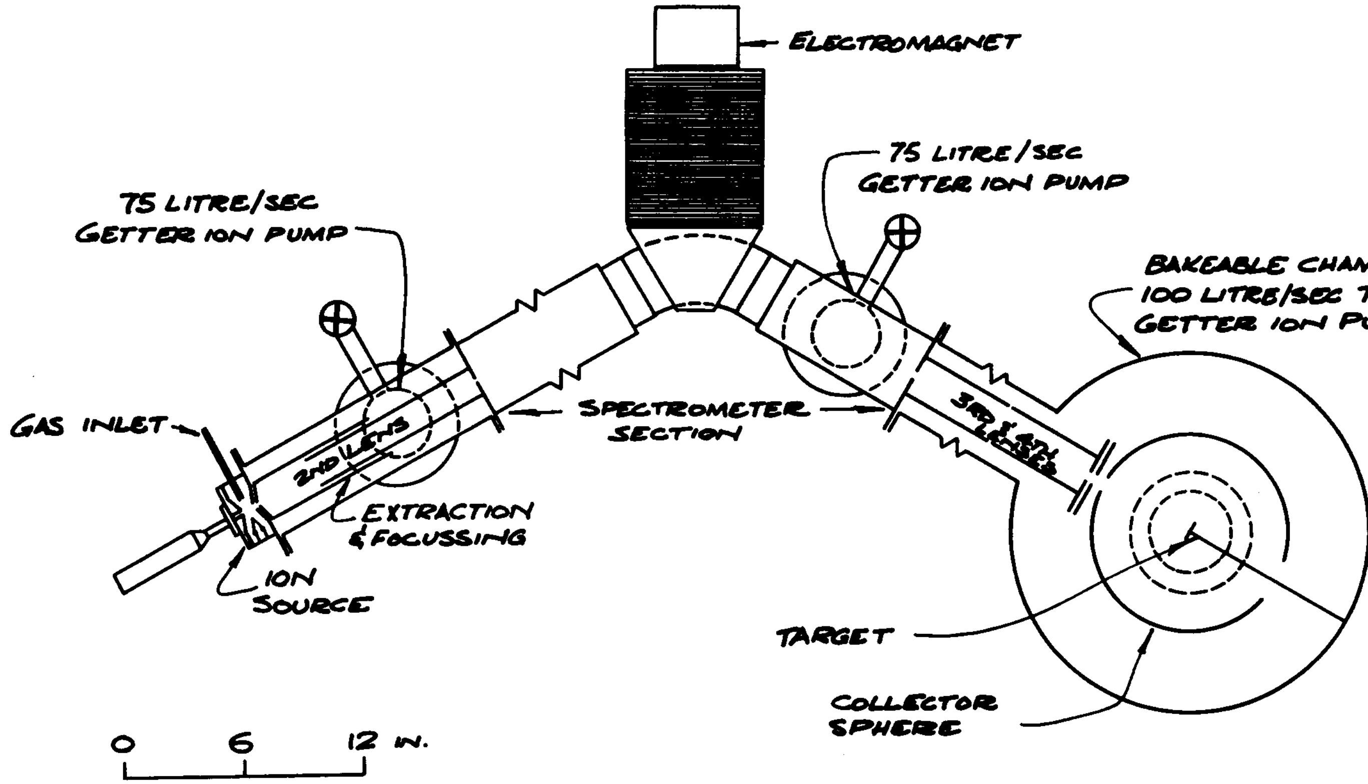


FIG. J-5.1

SCHEMATIC DIAGRAM OF THE LOW ENERGY ION BEAM APPARATUS.